Hosting Requirements
Smarter Balanced Assessment Consortium Contract 11 – Test Delivery System

American Institutes for Research

Revision History

Revision Description	Author/Modifier	Date
Initial Release	David Lopez de Quintana	October 14, 2013

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Purpose

This document is to assist states, software vendors and systems integrators in planning for delivery of Smarter Balanced assessments. The first year of operational testing will be in the 2014-2015 school year.

The Smarter Balanced interim and summative test system is composed of the following components:

- Assessment Creation & Management
- Assessment Delivery
- Assessment Reporting
- Shared Services

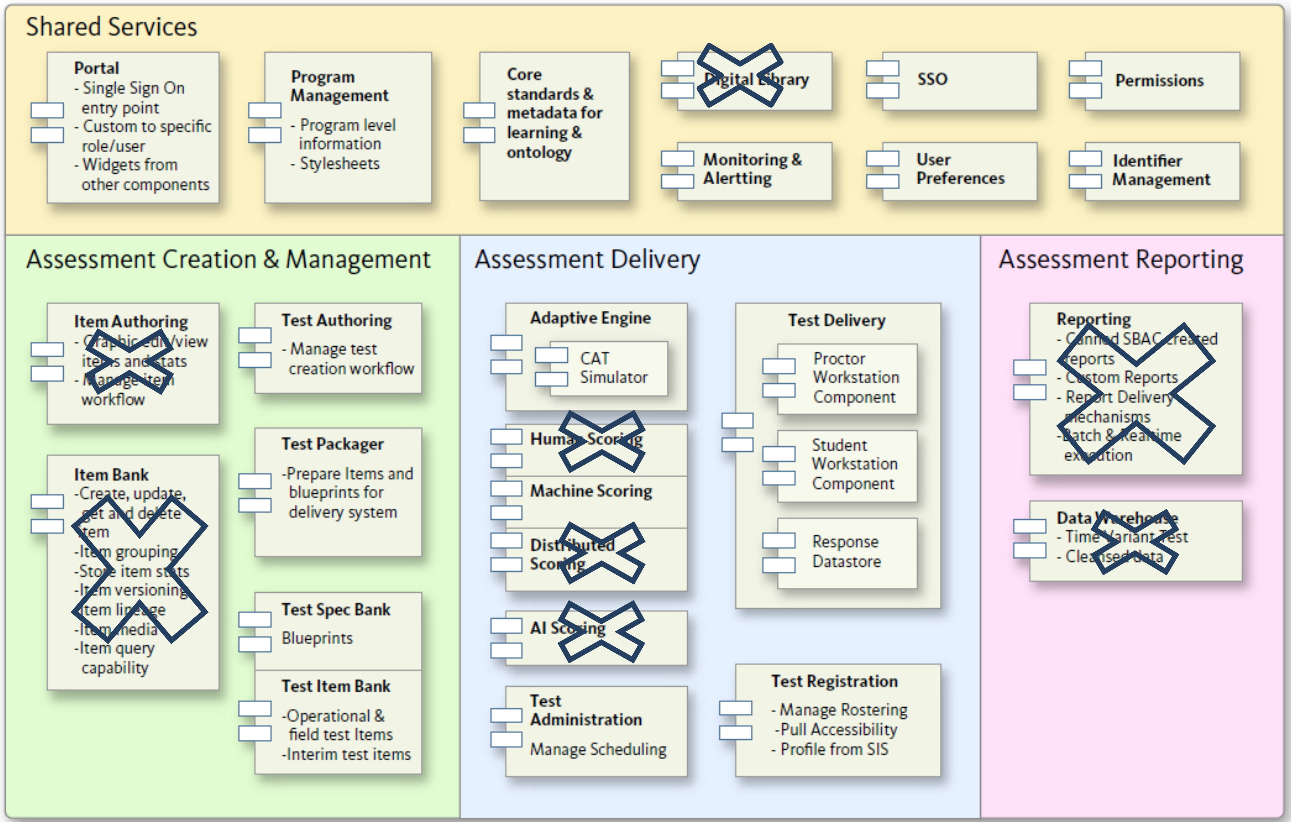
In addition to these components, Smarter Balanced is developing a Digital Library that will support teachers in planning formative assessment activities and in using the results of Smarter Balanced assessments to inform their practice.

The Smarter Balanced Assessment Consortium will host all of the above components with the exception of Assessment Delivery. The consortium will release an open source implementation of the assessment delivery system. States will be responsible for procuring assessment delivery from vendors who are certified to deliver Smarter Balanced assessments or for deploying their own instance of the open source system.

To assist states and potential partners in planning for that deployment, this document describes the hosting requirements of the open source implementation presently under development by the American Institutes for Research under Contract 11 with Smarter Balanced.

System Overview

The following diagram is Figure 4.2 from the Smarter Balanced System Architecture and Technology Report dated 21 March 2012. It depicts the components in the Smarter Balanced system. The components marked with an X are not part of Contract 11 and are developed by other Smarter Balanced vendors. Only the Contract 11 components (not marked with an X) will be analyzed in this document.



In addition to the above components, Smarter Balanced may authorize the development of two additional components: Test Integration and Test Scoring. Test Integration is responsible for receiving assessments from Test Delivery once the student completes real-time interactive portion of the assessment. It is responsible for sending items, rubrics and responses to various scoring engines including Hand Scoring and Distributed Scoring, and integrating these item scores with the items scored during the student assessment. The Test Scoring component is responsible for computing final test scores including scale scores.

Component Software

Development/Operation Software Packages

The following table summarizes the software technologies used by each component.

Software	Description
Oracle Java JDK	Software development language/platform
WordPress	WordPress Content Management System
Apache	Web server
Tomcat	Java Application Server
MySQL	Relational database engine

Software	Description
PHP	Software development language/platform
Spring Framework	Java development framework
Javascript	Client side scripting language
MongoDB	Non-relational database engine
Hyperic Server	Enterprise server monitoring
OpenOffice Calc	Open source spreadsheet application
OpenAM	Identity Management
OpenDJ	LDAP directory

Table 1. Development/Operation Software Packages

Software Packages by Component

The following table summarizes the component categories as described by Figure 1. Smarter Balanced Contract 11 Components. The category identifiers will be used in the table below for brevity.

Category Identifier	Component Category
1	Shared Services
2	Assessment Creation & Management
3	Assessment Delivery

Table 2. Component Categories

The following table summarizes the software components and the software technologies use in the development and operation of each component.

Category	Component	Java	Spring Framework	Javascript	WordPress	MySQL	MongoDB	PHP	OpenOffice Calc	Hyperic Server	Open AM	Open DJ
1	Portal	✓	✓		✓	✓		✓				
1	Program Management	✓	✓				✓					
1	Core Standards	✓	✓			✓			✓			
1	Monitoring and Alerting	✓	✓				✓			✓		
1	Single Sign On	✓	✓								✓	✓
1	Permissions	✓	✓			✓						✓
1	User Preferences	✓	✓				✓					

Category	Component	Java	Spring Framework	Javascript	WordPress	MySQL	MongoDB	PHP	OpenOffice Calc	Hyperic Server	Open AM	Open DJ
1	Identifier Management	✓	✓				✓					
2	Test Authoring	✓	✓									
2	Test Packager	✓	✓			✓						
2	Test Spec Bank	✓	✓			✓						
2	Test Item Bank	✓	✓				✓					
3	Test Delivery	✓	✓			✓						
3	Proctor Application			✓								
3	Student Application			✓								
3	Adaptive Engine	✓	✓			✓						
3	CAT Simulator	✓	✓			✓						
3	Machine Scoring	✓	✓									
3	Test Registration	✓	✓			✓					✓	✓
3	Test Administration	✓	✓			✓						
3	Test Integration	✓	✓			✓						

Category	Component	Java	Spring Framework	Javascript	WordPress	MySQL	MongoDB	PHP	OpenOffice Calc	Hyperic Server	Open AM	Open DJ
3	Test Scoring	✓	✓			✓						

Table 3. Components and Development/Operation Software Packages

Deployment Assumptions

This document assumes the following:

1. The deployment of the Smarter Balanced open source components being developed as part of various Smarter Balanced contracts, but focuses only on components being developed as part of contract SBAC-11, Test Delivery System.
2. Deployment on Amazon Web Services (AWS), including various AWS services such as Elastic Compute Cloud (EC2) and Amazon Relational Database Service (RDS). AWS is a robust, scalable and ubiquitous cloud infrastructure that provides virtual computing resources of a range of capabilities and prices.

Please note that the use of Amazon's AWS services is not strictly required, and other cloud infrastructures could be used instead of AWS. This document only analyzes the use of AWS as a reference deployment for pricing purposes.

Deployment Configurations

The deployment of the Smarter Balanced open source software is divided into several deployment units. Each deployment unit is meant to isolate several components and provide a computing environment tailored to their needs. The following table summarizes the deployment units.

Deployment Unit	Components Deployed	Description
Test Delivery	Test Delivery, Adaptive Engine, Machine Scoring (real-time item scoring only), CAT Simulator	The Test Delivery unit isolates the components that are responsible for interactive real-time management of student test sessions
Test Integration and Scoring	Test Integration, Test Scoring	The Test Integration and Scoring unit works closely with Test Delivery to manage student assessments once the interactive real-time aspect of a student assessment is complete
Test Registration and Administration	Test Registration, Test Administration	The Test Registration and Administration unit manages all aspects of student test registration and administration that are not already managed by the Test Delivery unit
Assessment Creation and Management	Item Authoring, Item Bank, Test Item Bank, Test Authoring, Test Spec Bank, Test Packager(Item Authoring and Item Bank from Smarter Balanced contract 07 should be deployed here)	The Assessment Creation and Management unit provides a computing environment for components that are used to create student assessments
SSO and Permissions	SSO, Permissions	The SSO and Permissions unit isolates components critical to the authentication and authorization function

Deployment Unit	Components Deployed	Description
Monitoring and Alerting	Monitoring and Alerting	The Monitoring and Alerting unit is isolated into its own unit to isolate other components from the significant system logging traffic
Shared Services	Portal, Program Management, Core Standards, User Preferences, Identifier Management	The Shared Services unit houses all remaining Shared Services components

Table 4. Summary of Deployment Groups

Test Delivery Unit

The following diagram represents the components of the Test Delivery deployment unit. We will use the Test Delivery deployment unit to illustrate features of the Amazon EC2 and RDS services.

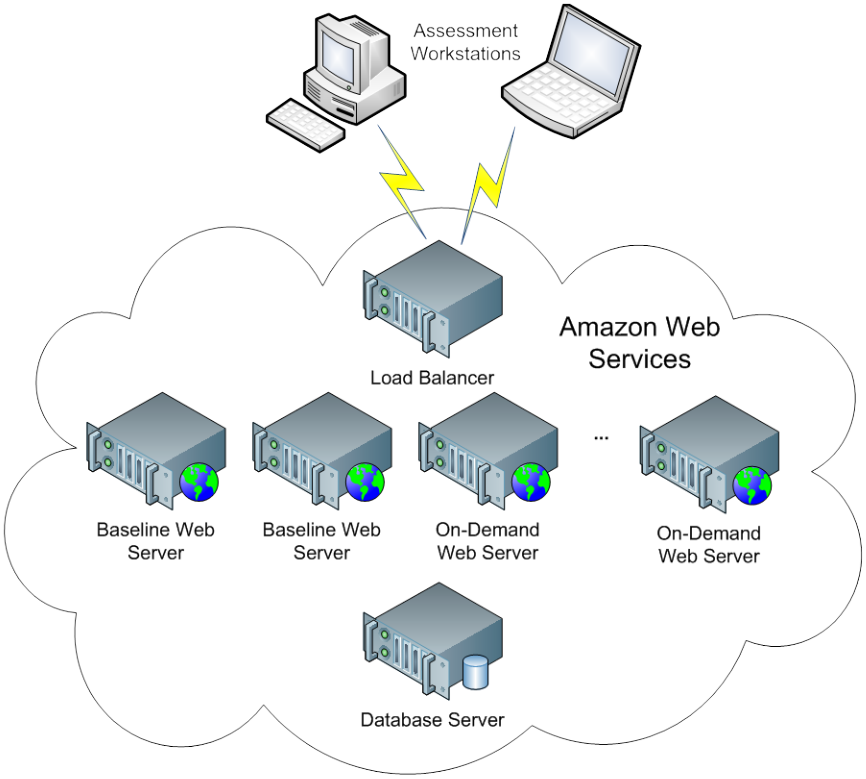


Figure 2. Test Delivery Unit Architecture

The Test Delivery unit assumes the following:

- An Elastic Load Balancer that distributes incoming application traffic across multiple Amazon EC2 instances
- Two baseline web servers – the baseline web server is an always-on application container that provides scalability for Test Delivery applications
- On-demand web servers – at peak load times, additional web server instances are created to handle the additional load

- Database server – an Amazon RDS for MySQL computing instance tailored for high performance database server operation

The following assumptions are made when selecting EC2 and RDS components.

Elastic Load Balancer

The baseline and on-demand web servers are deployed behind an instance of Elastic Load Balancer. The load balancer distributes incoming requests evenly to all baseline and on-demand web servers, ensuring that the deployment unit scales smoothly with increasing load. For increased fault tolerance, Amazon's Elastic Load Balancer is capable of detecting unhealthy web server instances and will stop directing incoming requests to them.

Load balancer costs are determined by the hour and by the amount of data served by the web servers through the load balancer. See the heading "Amount of Data Served" for more details on calculating the amount of data.

Web Server Instance Type

Each virtual computer created in the cloud of a particular configuration is known as an *instance*. Amazon EC2 currently offers the following instance types.

Instance Family	Instance Type	Processor Arch	vCPU	ECU	Memory (GiB)	Instance Storage (GB)	EBS-optimized Available	Network Perform-ance
General purpose	m1.small	32-bit or 64-bit	11	1	1.7	1 x 160	-	Low
General purpose	m1.medium	32-bit or 64-bit	1	2	3.75	1 x 410	-	Moderate
General purpose	m1.large	64-bit	2	4	7.5	2 x 420	Yes	Moderate
General purpose	m1.xlarge	64-bit	4	8	15	4 x 420	Yes	High
General purpose	m3.xlarge	64-bit	4	13	15	EBS only	Yes	Moderate
General purpose	m3.2xlarge	64-bit	8	26	30	EBS only	Yes	High
Compute optimized	c1.medium	32-bit or 64-bit	2	5	1.7	1 x 350	-	Moderate
Compute optimized	c1.xlarge	64-bit	8	20	7	4 x 420	Yes	High
Compute optimized	cc2.8xlarge	64-bit	32	88	60.5	4 x 840	-	10 Gigabit4

Instance Family	Instance Type	Processor Arch	vCPU	ECU	Memory (GiB)	Instance Storage (GB)	EBS-optimized Available	Network Perform-ance
Memory optimized	m2.xlarge	64-bit	2	6.5	17.1	1 x 420	-	Moderate
Memory optimized	m2.2xlarge	64-bit	4	13	34.2	1 x 850	Yes	Moderate
Memory optimized	m2.4xlarge	64-bit	8	26	68.4	2 x 840	Yes	High
Memory optimized	cr1.8xlarge	64-bit	32	88	244	2 x 120 SSD	-	10 Gigabit4
Storage optimized	hi1.4xlarge	64-bit	16	35	60.5	2 x 1,024 SSD2	-	10 Gigabit4
Storage optimized	hs1.8xlarge	64-bit	16	35	117	24 x 2,0483	-	10 Gigabit4
Micro instances	t1.micro	32-bit or 64-bit	1	Variable5	0.615	EBS only	-	Very Low
GPU instances	cg1.4xlarge	64-bit	16	33.5	22.5	2 x 840	-	10 Gigabit4

*1 CC2 and CR1 Instances are backed by 2 x Intel Xeon E5-2670 processors, eight-cores with hyperthreading

*2 CG1 Instances are backed by 2 x Intel Xeon X5570, quad-core with hyperthread plus 2 NVIDIA Tesla M2050 GPUs

*3 HI1 Instances can deliver more than 120,000 4 KB random read IOPS and between 10,000 and 85,000 4 KB random write IOPS (depending on active logical block addressing span) to applications. The maximum sequential throughput on is approximately 2 GB/s read and 1.1 GB/s write.

*4 HS1 Instances can deliver 2.4 GB/s of 2 MB sequential read performance and 2.6 GB/s of sequential write performance.

*5 Instances launched into the same cluster placement group are placed into a non-blocking 10 Gigabit ethernet network

*6 For more information on the Micro instances see the

Table 5. EC2 Instance Types

The general purpose m1.xlarge instance type is selected for baseline and on-demand web servers for its high network performance. It represents a reasonable trade-off of compute capacity, memory, storage, and cost ($0.48 per hour). EC2 instances incur costs for each hour or fraction of an hour the virtual computer is powered up and operating.

In addition to selecting the web server instance type, the web server operating system is also selected. Amazon EC2 offers preconfigured Amazon Machine Instances (AMI) to select from. AMIs come in many operating systems and various flavors of each operating system. Smarter Balanced

Contract 11 components are intended to run on the Linux operating system, and Linux comes prepackaged in various flavors known as distributions. Some of these distributions are enterprise versions that require paid support (Red Hat and SUSE Enterprise, for example) and some are community versions that are free to download and use (Fedora, CentOS, for example). The Ubuntu Server distributions are the same for enterprise and community users but offer paid support as an option.

Some enterprise distributions place restrictions on changing any of the software components provided in the distribution, and these are updated only when the distribution is updated in periodic release cycles. This means that certain components such as the Java Virtual Machine (JVM) may be older and may lack desirable features available in later versions. With Red Hat and SUSE Enterprise Linux, there is no option to upgrade components without voiding the support agreement.

Canonical Inc., the company that packages the Ubuntu Linux distribution, allows modifications to the preloaded components and provides cloud support for up to 100 virtual cloud servers for a reasonable cost. For this reason, AIR has selected the Ubuntu Server version 13 Linux distribution for this project.

Once a web server instance is created, it can be customized with deployments of software packages and Smarter Balanced components. This is done for each type of deployment, and the resulting customized virtual server is stored as a custom AMI. This way, additional identical copies of baseline and on-demand instances can be easily created. The baseline web server instances are left running for continuous availability, but the on-demand instances are powered up as needed to satisfy peak demand and shut down during off-peak periods to save money.

Unless otherwise indicated, web servers do not require persistent storage. Once a web server AMI is created, starting a new instance from the AMI creates a new virtual web server that is identical to the stored AMI. On the other hand, database server instances do require persistent high performance database storage.

Number of Baseline Web Servers

The number of baseline web servers is selected to ensure that adequate baseline capacity is available when demand starts to increase. For the Test Delivery unit, the number of baseline web servers selected is two to ensure fault tolerance. For other components with less critical response time and fault tolerance requirements, one baseline web server is adequate.

Number of On-Demand Web Servers

The number of baseline and on-demand web servers for the Test Delivery deployment unit is selected based on the expected number of students that will be taking assessments concurrently. We are using 5,000 students per web server as a rule of thumb. Two baseline web servers will therefore handle 2 x 5,000 = 10,000 concurrent students. If more than 10,000 concurrent students are needed, additional on-demand web servers are required for peak periods.

On-demand web servers can be provisioned at peak demand hours and days. The specific hours and days are dependent on a given deployment's expectations for the number of testing hours per day and days per year. For example, a client may plan for 8 testing hours per day and 120 total testing days per school year.

Amount of Data Served

For the Test Delivery deployment unit, the data required is calculated as follows:

Total Data Served = Number of concurrent students X average number of items served per student per hour X average size of item served X oerhead factor

For example:

Total Data Served = 15,000 concurrent students X 20 items per student per hour X 50KB per item X 125% / KB per GB

= 17.88 GB per hour

≈ 18 GB/hour

Data served is charged separately as a standalone expense and as part of the cost of running an Elastic Load Balancer. The amount of data served should be planned out based on the peak data demands and pro-rated for the number of hours and days of peak data demand.

Database Server Instance Type

Database server instances are selected from Amazon's Relational Database Service. These are high-performance instance types that are preconfigured with appropriate database engines and provide high availability features. For example, RDS instances are available in "Multi-Availability Zone Deployments." Availability Zones (AZ) are regions where Amazon maintains data centers such as the Easter region in Northern Virginia. These types of instances are provided with a second standby instance in a different AZ in case of AZ failure.

The following DB instances classes are available:

- Micro DB instance: 613 MB memory, up to 1 ECU, 64-bit platform, Low I/O Capacity
- Small DB instance: 1.7 GB memory, 1 ECU (1 virtual core with 1 ECU), 64-bit platform, Moderate I/O Capacity
- Medium DB instance: 3.75 GB memory, 2 ECUs (1 virtual core with 2 ECUs), 64-bit platform, Moderate I/O Capacity
- Large DB instance: 7.5 GB memory, 4 ECUs (2 virtual cores with 2 ECUs each), 64-bit platform, High I/O Capacity
- Extra Large DB instance: 15 GB of memory, 8 ECUs (4 virtual cores with 2 ECUs each), 64-bit platform, High I/O Capacity
- High-Memory Extra Large Instance: 17.1 GB memory, 6.5 ECU (2 virtual cores with 3.25 ECUs each), 64-bit platform, High I/O Capacity
- High-Memory Double Extra Large DB instance: 34 GB of memory, 13 ECUs (4 virtual cores with 3.25 ECUs each), 64-bit platform, High I/O Capacity
- High-Memory Quadruple Extra Large DB instance: 68 GB of memory, 26 ECUs (8 virtual cores with 3.25 ECUs each), 64-bit platform, High I/O Capacity
- High-Memory Cluster Eight Extra Large DB instance: 244 GB of memory, 88 ECUs (32 virtual cores with 2.75 ECUs each), 64-bit platform, High I/O Capacity.

The Multi-AZ High-Memory Quadruple Extra Large DB Instance is selected for the Test Delivery deployment unit for high performance and high availability.

Database Server Persistent Storage and Provisioned IOPS

Database server persistent storage can be selected in sizes between 100GB and 3TB, and with up to 30,000 provisioned IOPS. The amount of provisioned IOPS for MySQL should be selected to be within a 3:1 and 10:1 ratio of IOPS to storage size. For example, a 100 GB storage size should be provisioned with an IOPS between 300 (3/1) and 1,000 (10/1) IOPS.

When selecting database instances for use with Provisioned IOPS, Amazon recommends the following:

> *If you are using Provisioned IOPS storage, we recommend that you use the m1.large, m1.xlarge, m2.2xlarge, m2.4xlarge, or cr1.8xlarge instance classes. These instance types are optimized for Provisioned IOPS storage; other instance types are not. In addition, the available network bandwidth for Provisioned IOPS for m1.large instance class is 500 megabits per second (Mbps) compared to 1000 Mbps for an m1.xlarge, m2.2xlarge, or m2.4xlarge instance. As a result, for a similar IOPS-intensive workload, the number of realized IOPS for m1.xlarge, m2.2xlarge, m2.4xlarge, and cr1.8xlarge will be higher than that of m1.large.*
> *://docs.aws.amazon.com/AmazonRDS/latest/UserGuide/USER_PIOPS.html#USER_PIOPS.*

For this reason, only the four instance types are selected for database servers when high transactional performance is required. When the highest performance is required, only one of the four top instances mentioned above is selected.

Each of these database instances provides high performance and scale, but the scale is limited by the speed of the persistent database storage. The following applies to MySQL:

> *The following table shows the page size and the theoretical maximum IOPS rate for each DB engine. IOPS rates are based on the m2.4xlarge instance class with full duplex and a workload that is perfectly balanced between reads and writes. The SQL Server limit of 10,000 is due to the current storage limit of 1 TB and the current maximum IOPS to storage ratio of 10:1.*

DB Engine	Page Size	Maximum IOPS Rate
MySQL	16 KB	20,000
Oracle	8 KB	25,000
SQL Server	8 KB	10,000

> *://docs.aws.amazon.com/AmazonRDS/latest/UserGuide/USER_PIOPS.html#USER_PIOPS.*

AIR's experience shows that one concurrent student can be supported per IOPS. Given that the maximum expected performance is 12,500 IOPS for MySQL, AIR recommends that no more than 20,000 concurrent students be supported with a single-instance deployment of an Amazon RDS database server. For scale beyond 20,000 concurrent students, AIR recommends one additional Test Delivery deployment group per every additional 20,000 concurrent students. This will also require partitioning the student registration data according to partitioning criteria such as geography.

If 20,000 Provisioned IOPS is the target number of IOPS for the Test Delivery data store, Amazon recommends that the data store be within a 3/1 and a 10/1 ratio of provisioned IOPS to storage size. Therefore, 20,000 provisioned IOPS / 10 = a lower limit of 2,000 GB of storage. Although this is more storage than is required for Test Delivery, the Test Delivery database storage size is selected to be 2,000 GB to be consistent with 20,000 provisioned IOPS.

Test Integration and Scoring Deployment Unit

The Test Integration and Scoring deployment unit supports the Test Delivery deployment unit with test integration and scoring services. This unit receives the student assessment once the interactive real-time highly transactional part of the student assessment is complete. This unit receives results from hand scoring and other scoring engines and integrates these scores with the other assessment items scored in real time during the student assessment. Once a student assessment is completely integrated, the assessment is scored (including determination of scale scores) according to the configured scoring rules.

The following is a summary of the Test Integration and Scoring deployment unit selections.

Deployment Selection	Description
Elastic Load Balancer	An Elastic Load Balancer is required for this deployment unit.
Web Server Instance Type	An EC2 general purpose m1.xlarge instance is selected (64 bit, 4 virtual CPUs, 15GB of memory, 4x420GB of ephemeral storage, available EBS storage, and high network performance).
Number of Baseline Web Servers	Same scaling model as Test Delivery: two baseline web servers are selected for high availability and performance.
Number of On-Demand Web Servers	Same scaling model as Test Delivery: one on-demand web server is selected for increased load.
Amount of Data Served	Based on the number of concurrent students, the number of assessments completed per hour, the size of each assessment unit and an overhead factor. For example, for 10,000 concurrent students, one student assessment per hour, an assessment size of 20KB and an overhead factor of 25%, we have = 10,000 students X 50KB per student X 125% = 0.60GB/hour, or about 1 GB per hour.
DB Server Instance Type	A Multi-AZ Extra Large RDS database instance is selected. This server is not as large as the DB server selected for Test Delivery but reflects the lower activity expected for this server as compared to Test Delivery. It is optimized for Provisioned IOPS.
DB Server Storage	This storage size is selected based on the total number of students, the size of each test opportunity, the number of test opportunities, and an overhead figure. For example, = 500,000 students X 50KB per test opportunity X 3 opportunities per student X 125% overhead = 89.4GB Select a 200GB persistent store. Please note that this size will vary with the expected size of the deployment. A deployment with more students will require additional storage.
DB Server Provisioned IOPS	A 3/1 ratio of provisioned IOPS is selected. 200GB X 3 = 600 Provisioned IOPS

Table 6. Test Integration and Scoring Deployment Unit Summary

Test Registration and Administration Deployment Unit

The Test Registration and Administration deployment unit provides services for upload of entity, user and student files and a user interface for ad hoc modification of user roles,student demographics and accessibility tools information. The following selections are made for this deployment unit.

Deployment Selection	Description
Elastic Load Balancer	An Elastic Load Balancer is required for this deployment unit.
Web Server Instance Type	An EC2 general purpose m1.xlarge instance is selected (64 bit, 4 virtual CPUs, 15GB of memory, 4x420GB of ephemeral storage, available EBS storage, and high network performance).
Number of Baseline Web Servers	Two baseline web servers are selected for high availability and performance.
Number of On-Demand Web Servers	One on-demand web server is selected for periods of increased load during student registration and testing time.
Amount of Data Served	Test Registration and Administration functions consume a significant amount of data from various sources, but sends a similar amount of data to SSO, Test Delivery and Data Warehouse. For example, = 500,000 students X 50KB per student (leveled over 6 hours per day and 60 days per year) X 125% overhead for users and entities X 125% overhead
DB Server Instance Type	A Multi-AZ Extra Large RDS database instance is selected (IOPS optimized).
DB Server Storage	The database server storage size is proportional to the total number of students, the size of an average student record, an overhead factor to account for users and entities as a proportion of students, and the database overhead of storing a student record. For example: = 500,000 students X 50KB per student record X 125% user/entity factor X 125% database overhead factor = 37.25 GB, assume a safe size of database storage of 200GB
DB Server Provisioned IOPS	600 Provisioned IOPS are required for a factor of 3 to 1 Provisioned IOPS to storage size.

Table 7. Test Registration and Administration Deployment Unit Summary

Assessment Creation and Management Deployment Unit

This deployment unit is only required for entities that wish to have their own item authoring, test authoring and test packaging capabilities. The following selections are made for this deployment unit.

Deployment Selection	Description
Elastic Load Balancer	An Elastic Load Balancer is required for this deployment unit.
Web Server Instance Type	An EC2 general purpose m1.xlarge instance is selected (64 bit, 4 virtual CPUs, 15GB of memory, 4x420GB of ephemeral storage, available EBS storage, and high network performance).
Number of Baseline Web Servers	Two baseline web servers are selected for high availability and performance.
Number of On-Demand Web Servers	One on-demand web server is selected for periods of increased load during student registration and testing time.

Deployment Selection	Description
Amount of Data Served	Predicting the amount of data served by this deployment unit is TBD at this time. Assume 5 GB/hour for the time being.
DB Server Instance Type	A Multi-AZ Extra Large RDS database instance is selected (IOPS optimized).
DB Server Storage	DB server storage for this deployment unit varies based on the number of items and the average size of each item. Various multipliers apply such as: • A multiplier to account for various versions of an item • Number of test packages items are used in (items are replicated into each test package) • Database overhead For example, = 200,000 items X 50 KB per item X 5 item versions X 10 copies in Test Packages X 125% DB OH / 1024^2 KB per GB ≈ 597 KB. Assume 1,000 GB.
DB Server Provisioned IOPS	3,000 IOPS for a ratio of 3 to 1 Provisioned IOPS to storage size.

Table 8. Assessment Creation and Management Deployment Unit Summary

SSO and Permissions Deployment Unit

The SSO and Permissions deployment unit is different than other deployment units in that it utilizes an open source identity management system, OpenAM. Each instance of OpenAM includes the OpenDJ LDAP directory server. Therefore, no separate DB server instance is required. However, each web server instance requires persistent storage. This is different from web servers in other deployment units.

Deployment Selection	Description
Elastic Load Balancer	An Elastic Load Balancer is required for this deployment unit.
Web Server Instance Type	An EC2 general purpose 2nd generation double extra large instance is selected (64 bit, 8 virtual CPUs, 30GB of memory, EBS storage only, and high network performance).
Number of Baseline Web Servers	Two baseline web servers are selected for high availability and performance.
Number of On-Demand Web Servers	One on-demand web server is selected for periods of increased load during student registration and testing time.
Amount of Data Served	This varies according to the peak number of authentications per hour, the size in KB of each authentication, and an overhead factor. For example, = 10,000 authentications per hour X 50 KB per authentication X 150% overhead / 1024^2 GB per MB ≈ 1 GB/s
DB Server Instance Type	No DB server is required
DB Server Storage	Although no DB server storage is required, storage for the LDAP data store is required in each web server instance. For example, = 50,000 users X 50 KB per user X 150% DB overhead ≈ 4GB. Assume 50GB.

Deployment Selection	Description
DB Server Provisioned IOPS	500 IOPS for a ratio of 10 to 1 Provisioned IOPS to storage size for peak LDAP performance. Also include 200GB of Amazon S3 storage for snapshots for backup purposes (this is always included in the RDS database instance storage but is extra in standard EBS storage).

Table 9. SSO and Permissions Deployment Unit Summary

Monitoring and Alerting Deployment Unit

Monitoring and Alerting is similar to SSO and Permissions in that it uses an off the shelf open source monitoring solution called Hyperic for its function. It also has a custom component for storing logs and alerts. Therefore, no RDS database instance is required. Also, since Hyperic does not require multi-instance scaling (one instance is adequate for the number of servers in question), only one web server with persistent storage is required.

Deployment Selection	Description
Elastic Load Balancer	No load balancer required.
Web Server Instance Type	An EC2 general purpose m1.xlarge instance is selected (64 bit, 4 virtual CPUs, 15GB of memory, 4x420GB of ephemeral storage, available EBS storage, and high network performance).
Number of Baseline Web Servers	One baseline web server is required.
Number of On-Demand Web Servers	No additional on-demand web servers are required.
Amount of Data Served	This component is primarily a data sink rather than a data source. Assume 1GB/hour out for nominal usage.
DB Server Instance Type	A standard EC2 instance with EBS block storage will be used instead of a dedicated RDS database server instance. This choice is made because Hyperic has an embedded database and does not rely on RDS virtual hardware dedicated to a MySQL database.
DB Server Storage	Although no DB server storage is required, storage for Hyperic and custom log and alert data is required. This is difficult to predict, assume 250GB of standard EBS storage (as opposed to RDS DB server storage).
DB Server Provisioned IOPS	750 IOPS for a ratio of 3 to 1 Provisioned IOPS to storage size. Also include 350GB of Amazon S3 storage for snapshots for backup purposes (this is always included in the RDS database instance storage but is extra in standard EBS storage).

Table 10. Monitoring and Alerting Deployment Unit

Shared Services Deployment Unit

This deployment unit is used to house the remaining shared services other than SSO, Permissions and Monitoring and Alerting that do not require the same level of high availability, scalability and performance.

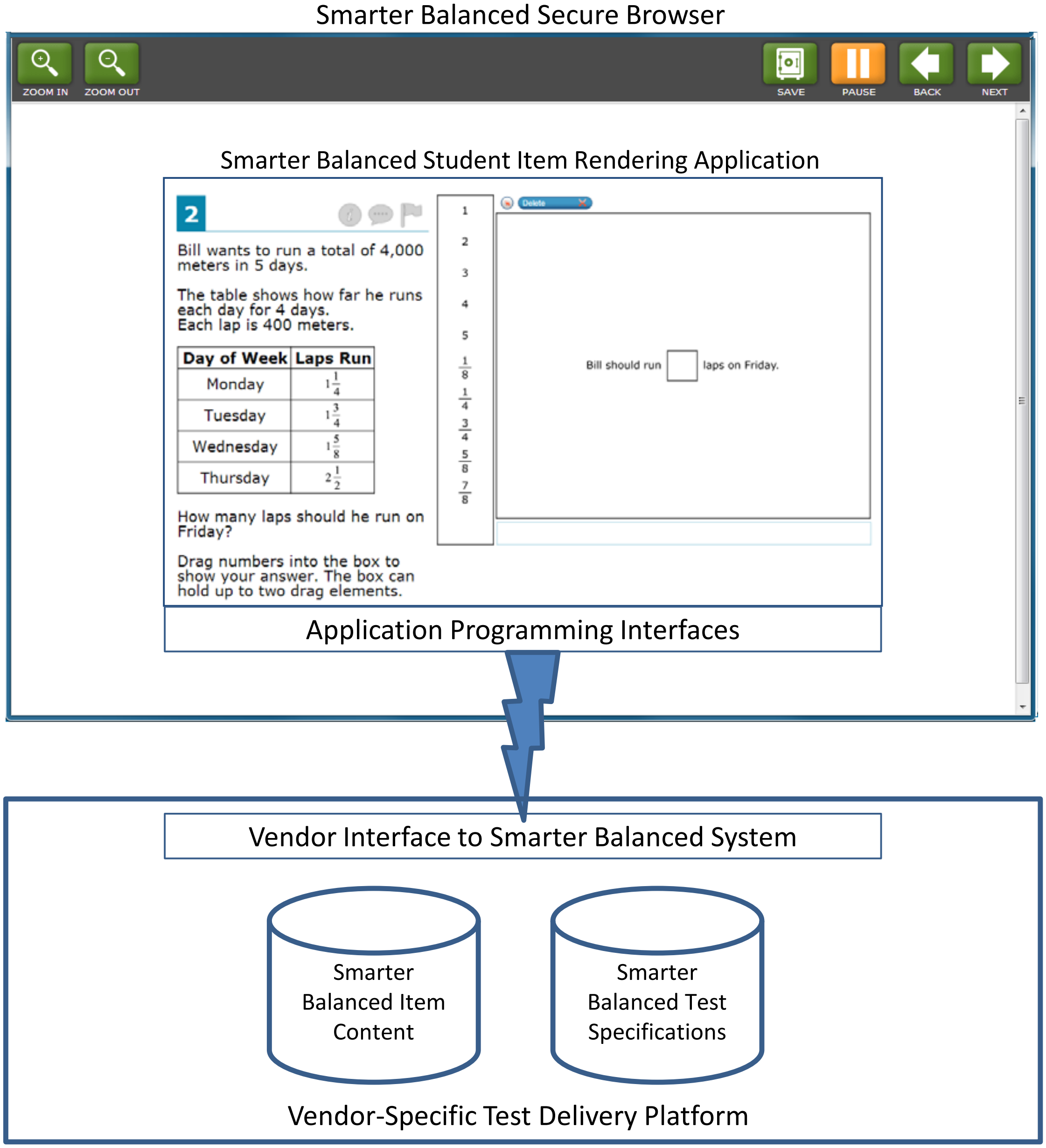
Deployment Selection	Description

Deployment Selection	Description
Elastic Load Balancer	No load balancer required.
Web Server Instance Type	An EC2 general purpose m1.xlarge instance is selected (64 bit, 4 virtual CPUs, 15GB of memory, 4x420GB of ephemeral storage, available EBS storage, and high network performance).
Number of Baseline Web Servers	Two baseline web servers are required.
Number of On-Demand Web Servers	One on-demand web server is required.
Amount of Data Served	Assume 1GB per hour, primarily for standards information stored in Core Standards.
DB Server Instance Type	A Multi-AZ Large RDS database instance is selected (IOPS optimized).
DB Server Storage	Assume minimum of 100GB of database storage.
DB Server Provisioned IOPS	300 IOPS for a ratio of 3 to 1 Provisioned IOPS to storage size.

Table 11. Shared Services Deployment Unit Summary

Alternative Deployment Scenario

Smarter Balanced is aware that some vendors may choose to certify alternative delivery systems rather than deploy the open source code base. To support that approach, Smarter Balanced will be releasing a Certification Package composed of all of the requirements, specifications, sample items and test harnesses necessary to certify a system for delivery of Smarter Balanced assessments. As Smarter Balanced is presently contracting out development of the certification package, delivery dates are not yet fixed. However, we expect the first specifications to become available before the end of Calendar Year 2013.One convenient way to adapt an existing test delivery system is to combine a vendor's existing test delivery server with the Smarter Balanced front-end. The following diagram illustrates this approach.


Smarter Balanced Secure Browser
ZOOM IN
ZOOM OUT
SAVE
PAUSE
BACK
NEXT
Smarter Balanced Student Item Rendering Application
2
Delete
1
2
3
4
5
$\frac{1}{8}$
$\frac{1}{4}$
$\frac{3}{4}$
$\frac{5}{8}$
$\frac{7}{8}$
Application Programming Interfaces
Vendor Interface to Smarter Balanced System
Smarter Balanced Item Content
Smarter Balanced Test Specifications
Vendor-Specific Test Delivery Platform

Bill wants to run a total of 4,000 meters in 5 days.

The table shows how far he runs each day for 4 days.
Each lap is 400 meters.

Day of Week	Laps Run
Monday	$1\frac{1}{4}$
Tuesday	$1\frac{3}{4}$
Wednesday	$1\frac{5}{8}$
Thursday	$2\frac{1}{2}$

How many laps should he run on Friday?

Drag numbers into the box to show your answer. The box can hold up to two drag elements.

Bill should run □ laps on Friday.

Figure 3. Alternative Approach Using Vendor-Specific Test Delivery Platform

In this scenario, test delivery vendors develop a Smarter Balanced-specific set of server-side interfaces that satisfy the application programming interface (API) requirements of Smarter Balanced Student Item Rendering Application and Secure Browser.

The Smarter Balanced Student Item Rendering Application is a Javascript client-side application that enables navigation and accurate item rendering for Smarter Balanced assessments. The Secure Browser is a special version of browser that limits student interactions outside of the assessment and provides certain accessibility features. Together, these two applications comprise the part of the assessment platform that runs on the student computer and that interacts with the student.

Not shown in this diagram is the Smarter Balanced Proctor Application, a client-side application similar to the Student application that is used by test administrators to create and manage test sessions that students can join. It also requires certain server side interfaces that are part of the vendor-specific interface.

This approach has the distinct advantage that the test delivery platform remains the same as the vendor's current proprietary test delivery platform. In order to take advantage of this alternative, a vendor will have to take the following steps:

1. Implement vendor interfaces to the Smarter Balanced Student and Proctor applications and the Secure Browser. This is necessary to present and render Smarter Balanced assessments that are indistinguishable to the test administrator and student. The uniformity of navigation and rendering provides a uniform assessment experience, maintaining the integrity of the Smarter Balanced assessments.
2. Consume Smarter Balanced items: Assessment item content and item assets would be made available by Smarter Balanced. Vendors will need to perform the appropriate translation between the item content and assets and provide the Student Application with correctly formatted XML. The Student Application will correctly render the items on the student's computer and provide the necessary student-facing navigation and features that the vendor interface satisfies.
3. Consume Smarter Balanced test specifications: Assessment packages will be provided that includes blueprints, scoring rules, reporting parameters and adaptive algorithm configuration. These test packages provide sufficient information for the vendor's proprietary assessment platform to deliver the Smarter Balanced assessments as designed.

Smarter Balanced is working on a complete set of specifications including APIs, item specifications and test specifications that vendors can use to adapt their assessment delivery platforms in this scenario. Smarter Balanced will announce the completion of the specifications and provide documentation and implementation guidelines as appropriate.

Cost Calculation Spreadsheet

A spreadsheet is provided embedded in the table below that calculates expected monthly and yearly costs. The spreadsheet accepts inputs that capture assumptions of the deployment and produce total costs based on the AWS prices at the time of this writing.

Cost Model Spreadsheet	Smarter Balanced Contract 11 Hosting F

Table 12. Cost Calculation Embedded Spreadsheet

The following is an example cost summary produced by this spreadsheet when key assumptions shown above are plugged in. This is a worse-case example using California student population numbers and assuming a 7.8% concurrent student load.

TOTAL COSTS PER MONTH

Monthly Costs	Test Delivery	Test Int & Scoring	Test Reg & Adm	SSO & Perm	Mon & Alerting	Shared Services	Assmt Creation & Mgmt	Total
Load balancer	1,678.60	293.58	263.64	32.97	0.00	19.97	31.64	2,320.40
Data transfer out	1,219.20	32.00	2,944.00	176.00	0.00	20.00	160.00	4,551.20
Baseline web server	9,838.08	9,838.08	702.72	1,464.00	351.36	702.72	702.72	23,599.68
On-demand web server	1,617.28	1,797.04	128.36	133.70	0.00	160.44	128.36	3,965.18
Web server storage	0.00	0.00	0.00	117.65	139.50	0.00	0.00	257.15
Database server	38,634.96	11,170.32	797.88	0.00	0.00	398.94	797.88	51,799.98
Database server storage	63,000.00	3,076.50	223.50	0.00	0.00	85.00	850.00	67,235.00
CloudWatch Monitoring	245.00	147.00	10.50	10.50	3.50	14.00	10.50	441.00
Subtotal	116,233.12	26,354.52	5,070.60	1,934.82	494.36	1,401.07	2,681.10	154,169.59
AWS Support Costs								10,791.88
Ubuntu Cloud Support Costs								666.67
Total								165,628.14

TOTAL COSTS PER YEAR

Monthly Costs	Test Delivery	Test Int & Scoring	Test Reg & Adm	SSO & Perm	Mon & Alerting	Shared Services	Assmt Creation & Mgmt	Total
Load balancer	20,143.20	3,522.96	3,163.68	395.64	0.00	239.64	379.68	27,844.80
Data transfer out	14,630.40	384.00	35,328.00	2,112.00	0.00	240.00	1,920.00	54,614.40
Baseline web server	118,056.96	118,056.96	8,432.64	17,568.00	4,216.32	8,432.64	8,432.64	283,196.16
On-demand web server	19,407.36	21,564.48	1,540.32	1,604.40	0.00	1,925.28	1,540.32	47,582.16
Web server storage	0.00	0.00	0.00	1,411.80	1,674.00	0.00	0.00	3,085.80
Database server	463,619.52	134,043.84	9,574.56	0.00	0.00	4,787.28	9,574.56	621,599.76
Database server storage	756,000.00	36,918.00	2,682.00	0.00	0.00	1,020.00	10,200.00	806,820.00
CloudWatch Monitoring	2,940.00	1,764.00	126.00	126.00	42.00	168.00	126.00	5,292.00
Subtotal	1,394,797.44	314,490.24	60,721.20	23,091.84	5,890.32	16,644.84	32,047.20	1,850,035.08
AWS Support Costs								129,502.56
Ubuntu Cloud Support Costs								8,000.00
Total								1,987,537.64

Table 13. Example Cost Summary from Spreadsheet

Please note that Amazon support costs of 10% of the subtotal and Ubuntu yearly support costs of $8,000 per year are factored in.